Articulation and Representation of Laterals in Australian-accented English

Jia Ying [1], *Jason A. Shaw*[2], *Catherine Best* [3], *Michael Proctor* [4], *Donald Derrick* [5], *Christopher Carignan*[6]
[1,2,3,6] Western Sydney U., [4]Macquarie U., [5] U. of Canterbury; j.ying@uws.edu.au

Laterals exhibit complicated patterns of articulation that make them ideal case studies for investigating basic principles of gestural coordination in speech. Prosodic structure and vowel context are known to affect the articulatory coordination of /l/ (Sproat & Fujimura, 1993; West, 1999; Wrench & Scobbie, 2003). English /l/ has been analyzed as consisting of two gestures whose timing varies systematically according to context (Browman & Goldstein, 1995). In Australian English, /l/ is realized with two main allophones: 'clear' [l] usually occurs in syllable onset, while 'dark' [ɫ] usually occurs in syllable coda (Cox, 2012). More recently, articulatory data has allowed a more refined characterization of /l/ variation than just two positional allophones. Most articulatory studies only record mid-sagittal data. A more complete understanding of /l/ requires knowledge of articulation in both the mid-sagittal plane and para-sagittal portions of the tongue.

To investigate the lateral dynamics of the tongue, we conducted a 3D EMA study collecting mid-sagittal and para-sagittal data concurrently. Five mono-lingual Australian English speakers (3 females and 2 males, age 19-36 years) were recorded. Three sensors were affixed mid-sagittally to the tongue tip (TT), tongue middle (TM), and tongue back (TB); two additional sensors were affixed para-sagittally to the sides of the blade (Figure 1). Target laterals were elicited in two vowel contexts (/æ/ and /ɪ/) and in two contrastive syllable positions: word-internal syllable-onset laterals in *CVC.**lVC*** frames, and internal syllable-coda laterals in ***CVl**.CVC* frames. Context vowels /æ/ and /ɪ/ were chosen because of the different constraints that they place on the shape of the tongue preceding /l/ (Stone & Lundberg, 1996). A vowel like /ɪ/ requires the tongue tip and tongue middle to raise (instead of lowering in the middle of the tongue in laterals). A vowel like /æ/ requires a complete groove shape such that the sides of the tongue are curved up (instead of curved down in laterals). By comparing /l/ production in the context of these two vowels, we investigate how local variation in tongue shape impacts the time course of lateralization. By comparing /l/ across syllable positions, we investigated how known variation in the timing and magnitude of mid-sagittal movements are related to para-sagittal dynamics.

We conducted three analyses of the data: 1) a mid-sagittal analysis designed to replicate past work, 2) a para-sagittal articulatory analysis designed to explore the dynamics of lateral side-branch formation, and 3) an angular analysis designed to provide converging evidence about tongue shape during /l/ production. For the mid-sagittal analysis, we measured the lag between TT and TM, TT and TB using the following formulas: TM Delay = TT Extremum - TM Extremum, TB Delay = TT Extremum - TB Extremum. A negative value indicates that the TT movement starts earlier than the TM or TB; a positive value indicates that the TM or TB movement is prior to TT movement. For the para-sagittal analysis, we computed an index of lateralization that captures the degree to which the sides of the tongue are higher or lower than the mid-sagittal plane, Δ Height = TT - TR/TL, and investigated how it changed over time. A positive ΔHeight value suggests tongue grooving, while a negative ΔHeight indicates mid-sagittal doming, which suggests lateralization (the blades are curved down). The duration of the lateralization interval indicates the time from the onset of lateralization to the point of most extreme lateralization as determined by ΔHeight. We also estimated mid-sagittal tongue curvature using an angular measurement. For this analysis, we extended two imaginary lines from the two para-sagittal sensors [tongue right (TR) and tongue left (TL)], to create a pseudo sensor (PS) between TR and TL sensors in the mid-sagittal plane (Figure 2). Then we computed Euclidean distances between all three points, and the angle PS using the law of cosines: cos(ps)= $|a^2 + b^2 - c^2|/|2ab|$(see Figure 2). An angle less than 180 indicates tongue grooving; while an angle greater than 180 indicates a tongue doming. We measured the change in this angle over time in each token. The angular lateralization interval is the interval spanning from when the angle increases beyond 180 degrees (onset of lateralization) to the time the angle returns to 180 degrees (offset of lateralization).

Results for the mid-sagittal analysis (Figure 3 & 4) replicated past studies. The TT-TM and TT-TB lags in syllable onset position were either near zero or negative, indicating that the tongue tip moves with or before the tongue middle/back. The TT-TM and TT-TB lags in syllable-final position were positive, indicating that the tongue middle/back movement is prior to the tongue tip movement. The difference between onset and coda position was significant and consistent across vowel environments.

Results from the second analysis indicate that the lateralization interval is affected by syllable position (Figure 5). Onset /l/s have shorter lateralization intervals than coda /l/s. This difference interacted with preceding vowel: in onset position, lateralization intervals were longer when preceded by /æ/ than by /ɪ/. Coda /l/ showed the opposite effect of vowel. The lateralization interval based on the tongue angle analysis (Figure 6) patterned with the interval based on ΔHeight, confirming that syllable position affected the time course of lateralization.

We have shown that tongue lateralization requires simultaneous retraction of the tongue back and advancement of the tongue tip. When TT and TB gestures are offset, as observed in coda position, it takes longer to form the side-branch characteristic of laterals, as indicated by the longer lateralization intervals found in coda position, than when TT and TD gestures are synchronous, as in onsets. Of our two indices of lateral dynamics, the angular interval is less variable than the ΔHeight interval, although they converge on the same characterization of laterals. Unlike the midsagittal sensors, the dynamics of the para-sagittal sensors were strongly influenced by the properties of the preceding vowels in a way that interacted with syllable position.

Figure 1. Schematic placement of tongue sensors

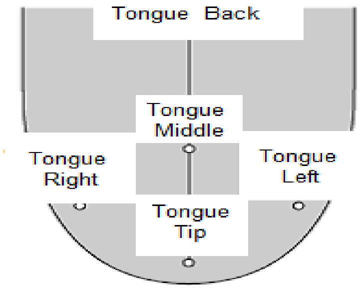


Figure 2. Illustration of angle analysis. Angle PS was obtained by calculating the Euclidean distance between TR to PS (a), TL to PS (b) and TR to TL (c). Then, we used the law of cosine to compute angle PS.

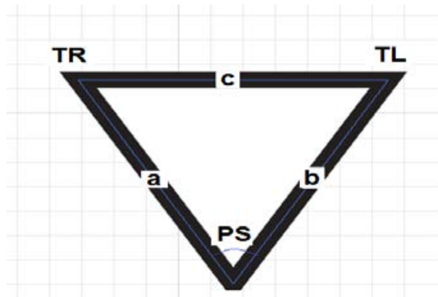


Figure 3. TT-to-TM lag for /l/ words in onset and coda position in /æ/ and /ɪ/ contexts.

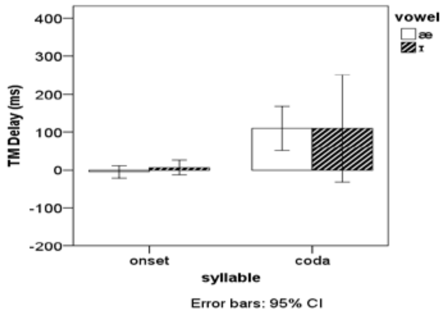


Figure 4. TT-to-TB lag for /l/ words in onset and coda position in /æ/ and /ɪ/ contexts.

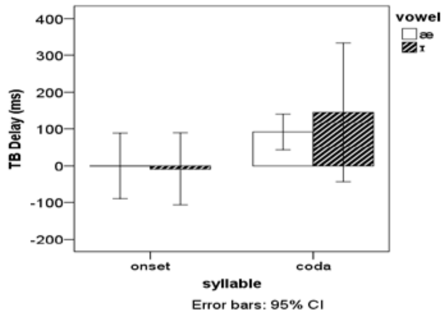


Figure 5. The mean lateralization interval for words preceded by /ɪ/ and /æ/ across syllable position based on tongue tip raising.

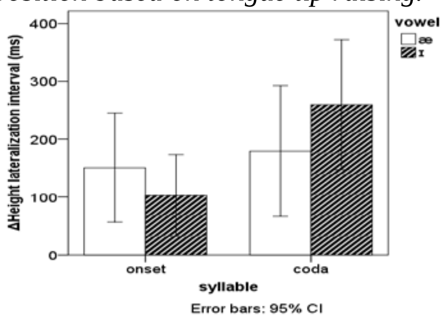
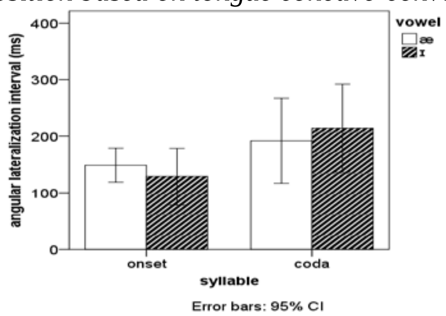


Figure 6. The mean lateralization interval for words preceded by /ɪ/ and /æ/ across syllable position based on tongue concave-convex patterns.



Selected reference: R. Sproat and O. Fujimura. "Allophonic variation in English /l/ and its implications for phonetic implementation," *Journal of phonetics*, vol. 21, no. 3, pp. 291-311, 1993